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ABSTRACT

A semi-permanent manned station in space--revisited and resupplied on a regular basis--has long been a major goal of space planners. Skylab has been a major step toward that goal. This overview will discuss Skylab contributions to technology and science and to our future in space.

INTRODUCTION

The objectives of Skylab were to carry out long duration tests of men and systems and to conduct a variety of basic and applied scientific investigations that require or benefit from man's presence in earth orbit. Summary findings to date in selected of these experiment areas have been presented in the preceding papers.

I'd like to discuss briefly some of the reasons for the Skylab configuration and then talk about overall significance of the findings as they appear today.

A basic guideline for Skylab was the use of Apollo and Saturn hardware wherever possible as opposed to developing completely new equipment. Thus, the crew were limited to three by the size of the Apollo Command Module which carries the crew to and from Skylab. The major living and working space for the 3-man crew was built from the third stage of the Saturn V rocket. Only two stages of rocket propulsion being necessary to get into earth orbit, it was a big simplification to use the third stage structure as the basic space station module and as it turned out this structure was a good size and shape for the mission.

The planned duration of the manned missions of 28 and 56 days came from an arbitrary medical limitation of a factor of two over prior experience. We had medical data from the Gemini Program for 14-days duration and on that basis we were willing to go an added 14 days. If the 28-day data showed that the crew came through in good shape, we were prepared to go an added 28 days for a nominal 56-day duration. Two 56-day missions were planned. After evaluating the data from the first 56-day mission (which was actually 59 days in duration as flown), we decided it was safe to go longer and we planned the third and last mission for 84-days duration which gave a total mission duration of 271 days--from May 14, 1973 to February 8, 1974. Men were aboard Skylab for 171 of those days. The orbital altitude of 270 miles (430 Km) was a compromise among payload capability of the launch vehicle, orbital lifetime of the spacecraft and radiation effects on film and crew. Similarly, the orbital inclination of 50^{o} to the Equator was a compromise among range safety, (not launching overland) payload capability and earth coverage. The selected 50^{o} allowed flight over about 90 percent of the earth population.

In the remainder of our discussion today, I plan to talk about some of the significant things we've learned from technology and engineering points of view and to summarize in a general way the significance of some of the experiment findings in the medical, solar physics, materials processing and earth resource areas which were presented in prior papers.

With regard to technology, I'd like to run through the major systems of Skylab with emphasis on those that represent significant advances.

ATMOSPHERIC CONTROL

Skylab represents our first experience in orbit with a two gas atmosphere; Mercury, Gemini and Apollo having all used pure oxygen. Because of the use of the existing command module as the ferry vehicle for the crew, we were limited to substantially less than full sea level pressure inside the Skylab. We found that we could provide full sea level pressure of oxygen and by adding 30 percent nitrogen, we could completely overcome some of the undesirable effects of long time exposure to pure oxygen. So the atmosphere is one third of an atmosphere total pressure but with a full one atmosphere partial pressure of oxygen. This has proven completely satisfactory in orbit. This approach of course has substantial weight savings. The one-third atmosphere Skylab contains about 350 pounds of oxygen and nitrogen compared with a weight of over 1000 pounds that would be required for a full one atmosphere. Over the length of the mission, including leakage and between mission evacuation, a weight savings of several thousand pounds was attained.

We've used for the first time a molecular sieve to remove carbon dioxide in contrast with the previously used lithium hydroxide expendable system. The molecular sieve results in major weight savings for long duration missions.

Thermal control of the atmosphere was a combination of direct solar heating supplemented by electrical heaters as required and worked well once we deployed the fabric sunshades to replace the original shield which was lost on the way to orbit.

ELECTRICAL POWER

In the area of electrical power, we employed previously used technology of fuel cells, batteries and solar cells. Skylab with its 25 KW capability represented by far the largest electrical system flown in space and has demonstrated feasible power management with a complex hybrid system. It also demonstrated again the importance of adequate reserve capacity and redundancy, with our initial power limited to one half of design capacity and after deployment of the stuck solar array to about 75 percent. At the 75 percent power level, we had no significant limitation in our ability to carry out the mission as planned. And incidentally, proponents of non-identical redundancy, that is making redundant systems of different configurations, can find lots from Skylab to support their arguments.

STABILIZATION AND ATTITUDE CONTROL

In the area of stabilization and attitude control, Skylab has demonstrated a significant advance in the state-of-the-art. This was our first flight application of large control moment gyroscopes to provide the muscle to control attitude of the spacecraft. Once each orbit, while on the dark side of earth, the momentum accumulated in holding attitude on the sun side was unloaded against gravity gradient torque through an on-board digital computer controlled program. The stabilization system exceeded its specified performance and has given us better than one arc second pointing control--which amounts to staying precisely pointed at a dime-sized target at a distance of two miles. Again, the importance of redundancy was demonstrated. One of the three CMG's had a bearing failure after six months operation but the system was designed to operate on two if necessary and operated successfully through the end of the mission in that mode. Supplemental control was by nitrogen gas jets which provided high torque for rapid maneuvering and docking loads.

CONTAMINATION

One of our major concerns early in the Program was possible contamination effects of man's life support systems on certain of the delicate Skylab instruments--that is, deposition of contaminants on optical surfaces and so forth. There also was concern about the effect of such contamination on the local atmosphere and the possible clouding effect on observations from Skylab. We took special pains in designing our trash handling system to control all vents with traps and fine filters and prevent dumping of solid particles, as well as limit outgassing of Skylab materials. Special instrumentation was carried to monitor such contamination and I'm glad to say that these control measures worked. The environment outside Skylab was as clean as or cleaner than any other spacecraft flown and contaminants were negligible. We now know that contamination from manned spacecraft need not be a problem to scientific observations and instrumentation.

HABITABILITY

Skylab included a number of advances in habitability. Firsts include "modern plumbing" with hot and cold running water, commode and shower, earth-like meals with frozen food, a trash disposal facility, private sleeping quarters, air conditioning, picture windows for earth viewing, and recreation and exercise facilities. All of these worked well and contributed significantly to crew comfort and well-being.

IN-FLIGHT MAINTENANCE AND REPAIR

A major yield from Skylab regards in-flight maintenance and repair. A sizeable program of planned maintenance was included in Skylab for replacement of wearout and replenishment items. A 60-pound tool kit with 91 individual tools was included for general repair as were planned replacement items such as cameras, film, light bulbs and fan motors. Certainly however, we had no idea prelaunch that we would be deploying sunshades and solar panels outside the spacecraft by EVA and carrying up special tools designed, built and tested over a few days. Based on early experience in Gemini, we had approached EVA maintenance and repair activities cautiously. Our experience with the emergency repair of the solar array and sunshade and other items gave us new insight and confidence and will have far-reaching effects on the design approach to in-flight repair, servicing and assembly of future spacecraft. The following major unplanned in-flight repairs were made:

- Parasol sunshade deployed
- Solar array deployed by EVA
- Twin pole sunshade deployed by EVA
- Erratic gyroscopes replaced with "six pack"
- Stuck battery relay released
- Cooling system replenished
- Microwave antenna repaired by EVA
- Solar TV monitor replaced
- Thermal channel of multi-spectral scanner replaced
- Instrument doors opened and closed

In addition, a host of smaller repairs were made to keep individual equipment operable.

TRAINING

Of particular significance was the usefulness of the neutral bouyancy facility and trainers/simulators to allow crew members to work out repair procedures on the ground. In some cases, it was feasible to use these facilities to train the actual flight crew prior to lift off--in others, such as the solar array release, the procedures were deployed by the backup crew after the flight crew were already in orbit and relayed to the crew by teletype and voice description.

Let us turn now to a summary of the significance of the Skylab experiment findings:

In the biomedical area, it is somewhat difficult and arbitrary to separate the operationally important results from the scientifically important. Certainly, the long duration physiological effects of weightlessness on the Skylab crews are among the most important data to be gathered from Skylab. So far, the findings reveal no specific effects which set an upper limit on human exposure to weightlessness.

The importance of quantity and type of exercise in maintaining crew physical fitness in orbit has been verified and the usefulness of motion sickness medication to facilitate rapid crew adaptation to zero gravity in large volume spaceships has been shown.

Turning now to solar physics, the sun is the source of all of our energy here on earth, and the importance of understanding the physics of this basic life support system of our earth is obvious. Seven major solar oriented instruments on Skylab have provided a wealth of superb data across the solar spectrum and the sun cooperated by showing unexpected bursts of activity during the mission. Solar physicists say confidently that much of present theory about the sun will require revision as a result of these Skylab observations. The significance to basic scientific knowledge is obvious. The full scope of practical benefits of this vastly expanded knowledge of our life giving sun will unfold over the coming years.

The earth resource data returned by Skylab have provided a wealth of information about our earth and its resources and a number of significant discoveries of important earth features and phenomena. These data are also key factors in pointing the best approach to future operational systems in the field of space applications.

In the materials processing area, it was theorized that zero gravity conditions should permit the formation of alloys, composites and crystals which are impossible on earth or of a homogeneity and perfection far greater than obtainable here on earth and, therefore, with valuable material properties not attainable on earth. First looks at specimens returned so far indicate that the expected beneficial effects are indeed there. Single crystals of complex substances have been grown in Skylab that are considerably larger than any grown on earth. Although much analysis remains, these findings are indeed exciting and could have practical value beyond that which we can now conceive.

There were other important areas of experimentation on board Skylab which we did not have time to cover during this brief symposium. These included:

- Studies of Comet Kohoutek

- Studies of Buck-Rogers flying belt-like devices for personal transportation in space.

- A series of experiments conceived by high school students typified by an investigation of the ability of spiders to spin their webs in zero gravity.

- A number of space physics and engineering investigations which require or benefit from man on-site participation.

These results, as well as expanded discussion of the areas covered here, will be presented in a number of specialist symposia during the coming years.

We have concluded the operational phase of Skylab, but the analysis, reporting and use of the information returned is just beginning.

We've recounted here the significance as it now appears in a number of specific areas. Perhaps, most significant is the finding of no physical limitation to man's ability to perform effectively in space for long periods and the demonstration anew that man can persevere and succeed in the face of adversity and can accomplish even the most difficult goals he has set for himself in exploring and using space to his benefit.